

Energy levels, radiative rates and lifetimes for transitions in Br-like ions with $38 \leq Z \leq 42$

Kanti M Aggarwal and Francis P Keenan

Astrophysics Research Centre, School of Mathematics and Physics, Queen's University Belfast, Belfast BT7 1NN, Northern Ireland, UK

e-mail: K.Aggarwal@qub.ac.uk

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Abstract

Energy levels and radiative rates for transitions in five Br-like ions (Sr IV, Y V, Zr VI, Nb VII and Mo VIII) are calculated with the general-purpose relativistic atomic structure package (GRASP). Extensive configuration interaction has been included and results are presented among the lowest 31 levels of the $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s 4p^6$ configurations. Lifetimes for these levels have also been determined, although unfortunately no measurements are available with which to compare. However, recently theoretical results have been reported by Singh *et al* [Phys. Scr. **88** (2013) 035301] using the same GRASP code. But their reported data for radiative rates and lifetimes cannot be reproduced and show discrepancies of up to five orders of magnitude with the present calculations.

1 Introduction

Laboratory measurements for the spectra of Br-like ions with $38 \leq Z \leq 42$ have been made by several workers, due to their relevance to studies of fusion plasmas. For example, [1]–[3] observed many lines in the spectra of Sr IV, and [4]–[6] of Y V and Zr VI. Similarly, several lines of Nb VII and Mo VIII have been detected by [7]–[11]. These elements, particularly Mo, are used in tokamak reactor walls and radiation from low charge states of sputtered or evaporated high-Z metal ions, such as Mo VIII, provide a useful study of the spectra [12]–[13]. Measurements of energy levels have been compiled by the NIST (National Institute of Standards and Technology) team [14], and are available at their website http://physics.nist.gov/PhysRefData/ASD/levels_form.html. However, the corresponding theoretical work on these ions is very limited. Biémont *et al* [15] reported radiative rates (A- values) for the magnetic dipole (M1) and electric quadrupole (E2) transitions among the ground state levels ($4s^2 4p^5 \ ^2P_{3/2}^o - ^2P_{1/2}^o$) of several Br-like ions, including those considered here. However, such limited data for a single transition are not particularly useful for modelling applications, with a larger set of results required. Therefore, in a recent paper Singh *at al* [16] calculated energies for the lowest 31 levels, belonging to the $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s 4p^6$ configurations, of Br-like ions with $38 \leq Z \leq 42$. Furthermore, they listed A- values for E1 transitions, but only from the ground state $4s^2 4p^5 \ ^2P_{3/2,1/2}^o$ to higher lying levels, insufficient for detailed plasma modelling. More importantly, for the calculations they included limited CI (configuration interaction) whereas it is very important for Br-like ions as already demonstrated for another ion, namely W XL [17, 18]. Therefore, there is scope for improvement as well as an extension to their reported data.

For the calculations we have adopted the GRASP (general-purpose relativistic atomic structure package) code to generate the wavefunctions. This was originally developed by Grant *et al.* [19], has been updated by one of the authors (Dr. P. H. Norrington), is referred to as GRASP0 and is freely available at the website <http://web.am.qub.ac.uk/DARC/>. It is a fully relativistic code, based on the *jj* coupling scheme. Additional relativistic corrections arising from the Breit interaction and QED (quantum electrodynamics) effects are also included. Furthermore, this version yields comparable results with other revised ones, such as GRASP2K [20, 21].

2 Energy levels

Singh *at al* [16] performed two sets of calculations with differing amount of CI. In the first (GRASP1) they included only three basic configurations, namely $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s 4p^6$, while in the second (GRASP2a) they added a further five configurations, namely $4s^2 4p^4 4f$, $4s 4p^5 4d$, $4s 4p^5 4f$, $4s^2 4p^3 4f^2$ and $4s^2 4p^3 4d^2$. These 8 configurations generate 470 levels in total, listed in table 1. However, there are many more configurations, such as $4s 4p^5 5l$ and $4s^2 4p^4 5l$, whose energy levels closely interact and intermix with the 8 considered by Singh *at al*. Based on several tests with increasing amount of CI, we have identified 39 configurations whose energy levels are in the interacting range of energy, and hence are influential in improving the accuracy of the calculations. These configurations and their generated energy ranges are listed in table 1 for all five ions of interest, namely Sr IV, Y V, Zr VI, Nb VII and Mo VIII. We also note that other configurations (such as $3p^5 3d^{10} 4s^2 4p^6$, $3p^5 3d^{10} 4s^2 4p^5 4d$ and $3p^5 3d^{10} 4s^2 4p^5 4f$) have also been included in tests, but their impact on the lower energy levels is insignificant, mainly because they generate levels at much higher energy ranges. For example, their energy range is 19–22 Ryd for Sr IV and 29–36 Ryd for Mo VIII. Nevertheless, we discuss their impact later in the section.

In tables 2–6 we list our energy levels for ions with $38 \leq Z \leq 42$. Included in these tables are our results using two sets of configurations, i.e. 8 (GRASP2b) which are the same as those considered by Singh *at al* [16] and all 39 (GRASP3) listed in table 1. Furthermore, only the lowest 31 levels of the $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s 4p^6$ configurations are included in these tables, because Singh *at al* reported results only for these. The corresponding compiled energies of NIST are also provided in the tables to facilitate comparison. Furthermore,

the level orderings in these tables are the same as those by Singh *et al*, even though our calculations and the NIST compilations differ in a few instances – see for example, levels 29 and 30 of Zr VI in table 4. We also note that the identification of these 31 levels for ions with $38 \leq Z \leq 42$ is not as difficult as was the case for another Br-like ion, i.e. W XL [17, 18]. For this reason we do not provide mixing coefficients for these ions.

The discrepancies between the GRASP2a and GRASP2b energy levels are up to 0.15 Ryd for all ions. Such large discrepancies are *not* expected, particularly because (i) Singh *et al* [16] have adopted the same version of the GRASP code, (ii) have used the option of *extended average level* (EAL) as by us, and (iii) we are able to reproduce their results corresponding to the GRASP1 calculations for *all* ions. In general, their calculated energies are *lower* and hence closer to the NIST compilations, although differences are up to ~ 0.2 Ryd (i.e. $\sim 7\%$) for some levels. However, we are unable to reproduce their results, and hence have little confidence in their data. Nevertheless, the limited CI included in these GRASP2 calculations is not sufficient to provide accurate results as already stated in section 1. Therefore, our final results from a much larger calculation (GRASP3) are also listed in tables 2–6. The 39 configurations included in these calculations generate 3990 levels in total.

As a consequence of the increased CI in the GRASP3 calculations, energies for most of the levels have decreased, by up to ~ 0.2 Ryd for all ions. However, in comparison to the measurements the calculated energies remain higher, by up to ~ 0.2 Ryd (i.e. 5%), depending on the ion. Although we have included a large CI in these calculations, a few other configurations with $n > 5$ have been omitted, such as $4p^6 6\ell$. Therefore, to assess the accuracy of our results, we have also employed the *Flexible Atomic Code* (FAC) of Gu [22], available from the website <http://sprg.ssl.berkeley.edu/~mfgu/fac/>. This is also a fully relativistic code and provides a variety of atomic parameters. In particular, results obtained from FAC for energy levels and radiative rates are comparable to GRASP, as already shown for several other ions, see for example: Aggarwal *et al.* for Kr [23] and Xe [24] ions. Additionally, larger calculations can be performed with this code within a reasonable time frame of a few days. Thus results from FAC will be helpful in assessing the accuracy of our energy levels and radiative rates.

As with GRASP, we have also performed a series of calculations with the FAC code with increasing amount of CI, but focus only on three. These are (i) FAC1, which includes the same 470 levels as in GRASP2, (ii) FAC2, which includes the same 3990 levels as in GRASP3, and finally (iii) FAC3, which includes a total of 12,137 levels, the additional ones arising from the $4p^6 6\ell$, $4s4p^5 6\ell$, $4s^2 4p^4 6\ell$, $4p^6 7\ell$, $4s4p^5 7\ell$, $4s^2 4p^4 7\ell$, $4s^2 4p^3 5\ell^2$, $4s4p^4 5\ell^2$, $3p^5 3d^{10} 4s^2 4p^6$, $3p^5 3d^{10} 4s^2 4p^5 4d$ and $3p^5 3d^{10} 4s^2 4p^5 4f$ configurations. Results obtained from all three calculations are also listed in tables 2–6.

With the same levels of CI (i.e. GRASP2b and FAC1 and GRASP3 and FAC2) both sets of energies from two independent codes agree within 0.1 Ryd for all levels and all ions listed in tables 2–6. This is highly satisfactory and confirms, once again, that the energies reported by Singh *et al* [16] are difficult to understand. Energies obtained from calculations with larger CI (i.e. FAC3) agree with those from FAC2 to within 0.01 Ryd for all levels and ions. This clearly indicates that the CI included in our GRASP3 and FAC2 calculations is more than sufficient, and hence there is no need to include additional CI as far as the levels of the $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s4p^6$ configurations are concerned. In conclusion, all theoretical energies are higher than the NIST compilations and results obtained from our GRASP3 calculations are the closest. For most levels, the discrepancies between theory and measurements are small, but the differences are larger (up to ~ 0.2 Ryd or 5%) for some of the higher levels and hence this is also our assessment of the accuracy.

3 Radiative rates

Besides energy levels, radiative rates (A- values) are required for the modelling of plasmas. Generally, electric dipole (E1) transitions dominate in magnitude, but sometimes other types of transitions are also important and hence are preferred for a complete plasma model. Their availability is more important for the further calculations of lifetimes – see section 4. Therefore, we have also calculated A- values for the electric quadrupole

(E2), magnetic dipole (M1) and magnetic quadrupole (M2) transitions. For all types of transitions, the absorption oscillator strength (f_{ij}) and radiative rate A_{ji} (in s^{-1}) are related by the following expression:

$$f_{ij} = \frac{mc}{8\pi^2 e^2} \lambda_{ji}^2 \frac{\omega_j}{\omega_i} A_{ji} = 1.49 \times 10^{-16} \lambda_{ji}^2 \frac{\omega_j}{\omega_i} A_{ji} \quad (1)$$

where m and e are the electron mass and charge, respectively, c the velocity of light, λ_{ji} the transition energy/wavelength in Å, and ω_i and ω_j the statistical weights of the lower i and upper j levels, respectively. Similarly, if required, corresponding S- values can be obtained through Eqs. (2–5) of [25].

The A-, f- and S- values have been calculated in both Babushkin and Coulomb gauges, i.e. the length and velocity forms in the widely used non-relativistic nomenclature. However, the velocity form is generally considered to be comparatively less accurate and therefore we will present results in the length form alone, as did Singh *et al* [16]. Nevertheless, we will discuss later the velocity/length form ratio, as this provides some assessment of the accuracy of the results.

In tables 7–11 we compare our A- values from two calculations with the GRASP code (GRASP2b and GRASP3) with those of GRASP2a [16] for ions with $38 \leq Z \leq 42$. Also included in these tables are the f- values from our GRASP3 calculations, because they give an indication of the strength of a transition. Only transitions from the ground state levels $4s^2 4p^5 \ ^2P_{3/2,1/2}^o$ are included as these are the ones reported by Singh *et al* [16]. As for the energy levels, we cannot reproduce their A- values with the configurations they included. Differences of a factor of two between the two sets of A- values are common for many transitions and all ions – see for example, the 1–3/19 and 2–3/6/27 transitions of Sr IV in table 7. For some transitions, their A- values are lower whereas others are higher, and hence there is no systematic trend in the differences. Similarly, for a few transitions, discrepancies between the two sets of A- values are up to two orders of magnitude – see for example, 2–6 of Y V, Zr VI and Nb VII, in tables 8–10. However, for the 1–26 transition of Zr VI discrepancy is up to five orders of magnitude. Some of these transitions are *weak* ($f \sim 10^{-4}$ or less) and therefore some differences in the A- values are not unexpected, but not of orders of magnitude, particularly when the same atomic structure code and the same level of CI are used. Therefore, we do not discuss the A- values of Singh *et al* further and rather focus on the accuracy assessment of our results.

As noted in section 1 and discussed in section 2, the CI included in the GRASP2 calculations is insufficient for accurate determination of atomic parameters. Therefore, results obtained from our larger GRASP3 calculations should be comparatively more accurate, as for the energy levels. Differences between the GRASP2b and GRASP3 A- values are up to a factor of two for several transitions and in all ions – see for example, 1–5/7/10/11 of Sr IV in table 7. However, all such transitions have small f- values, and are more susceptible to varying amount of CI, due to cancellation or additive effects. Therefore, such discrepancies are very common [26]. For the same reason, differences between the two sets of A- values are larger (up to an order of magnitude) for some weaker transitions, such as 1–26 ($f = 5.5 \times 10^{-2}$), 2–6 ($f = 2.6 \times 10^{-5}$) and 2–14 ($f = 5.5 \times 10^{-5}$). Finally, discrepancies, if any, with the Biémont *et al* [15] A- values for the M1 and E2 ($4s^2 4p^5 \ ^2P_{3/2}^o - ^2P_{1/2}^o$) transitions are less than $\sim 10\%$ for all ions.

Also included in tables 7–11 are the ratio (R) of the velocity and length forms of A- values. For strong transitions ($f \geq 0.01$) R is within $\sim 20\%$ of unity, which is highly satisfactory. However, the 1–3 and 2–3 (i.e. $4s^2 4p^5 \ ^2P_{3/2,1/2}^o - 4s 4p^6 \ ^2S_{1/2}$) transitions are exceptions, because R is up to 0.5 depending on the ion. For these transitions CI is not very influential because the A- values from GRASP2b and GRASP3 are similar. Such discrepancies are often observed for even comparatively strong transitions. Moreover, different calculations with varying amount of CI may yield R closer to unity but strikingly different f- values in magnitude – see Aggarwal *et al* [27] for examples. Among the weaker transitions, discrepancies are up to an order of magnitude for a few, and the only exception is the 2–6 transition ($f \sim 10^{-11}$) of Zr VI for which $R = 1200$. Therefore, based on the ratio R and other comparisons discussed above, the accuracy of our listed results is assessed to be better than 20% for a majority of the transitions.

Since no other results of comparable complexity and accuracy are available for the A- values, we have undertaken calculations with FAC, because in general it generates results of comparable accuracy [27]. For

brevity, we include in Table 7 the A- values for transitions of Sr IV obtained from the FAC2 calculations, which include the same CI (3990 levels) as in GRASP3. Corresponding results from a larger calculation with 12,137 levels (FAC3) are also included in the table. For most (comparatively strong transitions with $f \geq 0.01$) the GRASP3 and FAC2 A- values agree within $\sim 20\%$, although differences of up to 50% are also noted for a few, such as 1–25/26 and 2–27. Differences are larger, up to a factor of 5, for a few weaker transitions – see for example 1–12 ($f \sim 10^{-5}$). Such differences between two independent calculations are not unexpected and have been noted in the past for several ions. Additionally, for the 1–14/15 transitions the A- values in FAC2 (and FAC3) appear to be interchanged, but not for 2–14/15. The effect of larger CI can be better understood with the comparison between the FAC2 and FAC3 A- values. For some weaker transitions, differences are again up to a factor of 5, and are up to 50% for a few stronger ones, such as 1–25/26/30 and 2–27. Surprisingly, for three of these transitions (except 1–30) the A- values from FAC3 are closer to GRASP3 than to FAC2. Similar differences between calculations with the GRASP and FAC codes are noted for transitions of other ions. Therefore, we have confidence in our GRASP3 calculations, and as already stated our accuracy assessment for a majority of (strong) transitions remains to be about 20%, although scope remains for improvement.

4 Lifetimes

The lifetime τ of a level j is defined as follows:

$$\tau_j = \frac{1}{\sum_i A_{ji}}. \quad (2)$$

In tables 12–16 we have listed lifetimes for all 31 levels of the $38 \leq Z \leq 42$ ions. Included in these tables are our results from the GRASP2b and GRASP3 calculations along with those of Singh *et al* [16], designated as GRASP2a. For our calculations, the contribution of all types of transitions (E1, E2, M1 and M2) are included. Additionally, we have also listed the A- values for the *dominant* transitions, i.e. all those which have a contribution of $\geq 20\%$ to $\sum A_{ji}$.

Unfortunately, the only other results for τ available for comparison are those of Singh *et al* [16], who have also included contributions from all four types of transitions, and have adopted the same version of the GRASP code as already stated. Their results are included in tables 12–16, but discrepancies with our calculations are up to four orders of magnitude for all ions – see for example, levels 24 of Sr IV, 20 of Y V, 26 of Zr VI, and 5 of Nb VII and Mo VIII. However, as the A- values of Singh *et al* are not considered to be reliable, as discussed in section 3, neither are the results for τ .

Since our GRASP3 calculations include larger CI, and the energy levels and A- values from these are comparatively more accurate, so should be the corresponding results for τ . Differences between GRASP2b and GRASP3 values of τ are generally within a factor of two, although discrepancies for a few levels, such as 10 of Sr IV and 26 of Y V, are up to two orders of magnitude. However, the dominant transitions for all such levels are invariably weak and hence less accurate, as already discussed in section 3. Further calculations and preferably future measurements of τ will be more helpful in assessing the accuracy of our results.

5 Conclusions

In this work, energy levels, radiative rates, oscillator strengths and lifetimes have been listed for transitions among the lowest 31 levels of Br-like ions with $38 \leq Z \leq 42$. These levels belong to the $4s^2 4p^5$, $4s^2 4p^4 4d$ and $4s 4p^6$ configurations, and for calculations the GRASP code has been adopted. Extensive comparisons have been made for all atomic parameters with the differing amount of CI as well as with similar calculations with the FAC code. Unfortunately the only prior results available for comparison are those of Singh *et al* [16], which are not re-produceable. Although differences with their energy levels are only up to 0.15 Ryd, the discrepancies for radiative rates and lifetimes are up to five orders of magnitude for several transitions (levels) and for all ions.

Differences between our energy levels calculated with a large CI and the measurements (compiled by NIST) are up to 0.2 Ryd ($\sim 5\%$) for a few, although the agreement is much better for most levels. Similarly, the accuracy for other parameters, namely A-, f- and τ values, is assessed to be better than 20% for a majority of (strong) transitions/levels. Finally, calculations for energies and A- values have been performed for up to 12,137 levels, although results have been discussed for only 31. Results for a larger number of levels and their corresponding transitions will be reported in a later paper.

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Table 1. Configurations of Br-like ions, their generated levels and energy ranges (in Ryd).

Index	Configuration	No. of Levels	Sr IV	Y V	Zr VI	Nb VII	Mo VIII
1	4s ² 4p ⁵	2°	0.0 – 0.1	0.0 – 0.1	0.0 – 0.1	0.0 – 0.2	0.0 – 0.2
2	4s ² 4p ⁴ 4d	28	1.8 – 2.6	2.1 – 3.0	2.4 – 3.5	2.7 – 3.9	3.0 – 4.3
3	4s ² 4p ⁴ 4f	30°	3.1 – 3.5	3.8 – 4.3	4.6 – 5.2	5.2 – 5.9	5.8 – 6.9
4	4s4p ⁶	1	1.5 – 1.5	1.7 – 1.7	1.9 – 1.9	2.1 – 2.1	2.3 – 2.3
5	4p ⁶ 4d	2	5.5 – 5.5	6.4 – 6.4	6.9 – 7.2	7.5 – 8.2	8.2 – 9.1
6	4p ⁶ 4f	2°	6.9 – 7.0	8.1 – 8.4	9.3 – 9.6	10.3 – 10.8	11.8 – 12.1
7	4s4p ⁵ 4d	23°	3.1 – 3.6	3.6 – 4.3	4.0 – 5.1	4.5 – 5.7	5.1 – 5.9
8	4s4p ⁵ 4f	24	4.6 – 5.7	5.5 – 6.9	6.5 – 8.0	7.4 – 8.1	8.3 – 9.0
9	4s ² 4p ³ 4d ²	141°	3.6 – 5.0	4.1 – 5.7	4.7 – 6.6	5.2 – 7.4	5.8 – 8.1
10	4s ² 4p ³ 4f ²	221°	6.5 – 7.2	8.0 – 8.6	9.4 – 10.3	10.7 – 11.8	12.0 – 13.6
11	4s ² 4p ³ 4d4f	363	4.9 – 6.1	6.0 – 7.3	7.0 – 8.6	8.0 – 9.9	8.9 – 11.4
12	4s ² 4p ² 4d ³	261	5.7 – 7.3	6.5 – 8.6	7.4 – 9.8	8.1 – 11.0	9.0 – 12.2
13	4s ² 4p4d ⁴	180°	8.2 – 9.7	9.5 – 11.3	10.8 – 12.9	11.8 – 14.4	13.1 – 16.0
14	4s ² 4p ² 4d ² 4f	1140°	7.0 – 8.5	8.3 – 10.2	9.5 – 11.6	10.7 – 13.4	11.9 – 15.2
15	4s4p ³ 4d ³	678°	6.5 – 9.2	7.4 – 10.7	8.4 – 12.2	9.3 – 13.7	10.3 – 15.1
16	4p ⁵ 4d ²	45°	6.8 – 7.5	7.7 – 8.4	8.7 – 9.6	9.6 – 10.8	10.6 – 11.8
17	3d ⁹ 4s ² 4p ⁵ 4d	96°	10.3 – 11.4	12.1 – 13.4	13.9 – 15.5	15.9 – 17.7	17.9 – 19.9
18	3d ⁹ 4s ² 4p ⁵ 4f	113	11.8 – 12.1	14.1 – 14.5	16.4 – 16.9	18.8 – 19.5	21.2 – 22.1
19	3d ⁹ 4s ² 4p ⁶	2	8.4 – 8.6	9.9 – 10.1	11.5 – 11.7	13.2 – 13.4	15.0 – 15.2
20	4s4p ⁵ 5s	7°	3.8 – 4.4	4.6 – 5.3	5.3 – 6.2	6.3 – 7.2	7.3 – 8.2
21	4s4p ⁵ 5p	18	4.1 – 4.8	5.0 – 5.8	5.9 – 6.8	6.9 – 7.8	7.9 – 9.0
22	4s4p ⁵ 5d	23°	4.6 – 5.3	5.7 – 6.4	6.8 – 7.6	7.9 – 8.8	9.1 – 10.1
23	4s4p ⁵ 5f	24	5.1 – 5.7	6.3 – 7.0	7.5 – 8.3	8.8 – 9.7	10.2 – 11.1
24	4s4p ⁵ 5g	24°	5.1 – 5.7	6.4 – 7.0	7.7 – 8.4	9.1 – 9.9	10.5 – 11.4
25	4p ⁶ 5s	1	6.0 – 6.0	7.1 – 7.1	8.2 – 8.2	9.3 – 9.3	10.5 – 10.5
26	4p ⁶ 5p	2°	6.3 – 6.3	7.4 – 7.6	8.7 – 8.7	9.8 – 10.0	11.1 – 11.2
27	4p ⁶ 5d	2	6.9 – 6.9	8.1 – 8.1	9.5 – 9.5	10.9 – 10.9	12.3 – 12.3
28	4p ⁶ 5f	2°	7.2 – 7.3	8.7 – 8.7	10.2 – 10.3	11.7 – 11.8	13.4 – 13.5
29	4p ⁶ 5g	2	7.3 – 7.3	8.8 – 8.8	10.4 – 10.4	12.0 – 12.0	13.7 – 13.7
30	4s ² 4p ⁴ 5s	8	2.2 – 2.6	2.8 – 3.3	3.5 – 4.0	4.2 – 4.8	4.9 – 5.6
31	4s ² 4p ⁴ 5p	21°	2.5 – 2.9	3.2 – 3.7	4.0 – 4.6	4.8 – 5.4	5.6 – 6.4
32	4s ² 4p ⁴ 5d	28	3.0 – 3.5	3.9 – 4.4	4.8 – 5.4	5.8 – 6.4	6.8 – 7.5
33	4s ² 4p ⁴ 5f	30°	3.5 – 3.9	4.5 – 4.9	5.4 – 6.2	6.7 – 7.4	7.8 – 8.6
34	4s ² 4p ⁴ 5g	30	3.5 – 3.9	4.6 – 5.0	5.7 – 6.2	6.9 – 7.5	8.1 – 8.8
35	3d ⁹ 4s ² 4p ⁵ 5s	23°	10.8 – 11.2	12.9 – 13.3	15.2 – 15.7	17.6 – 18.1	20.1 – 20.7
36	3d ⁹ 4s ² 4p ⁵ 5p	65	11.1 – 11.7	13.3 – 14.0	15.7 – 16.4	18.2 – 19.0	20.8 – 21.7
37	3d ⁹ 4s ² 4p ⁵ 5d	96°	11.7 – 12.1	14.1 – 14.6	16.6 – 17.2	19.2 – 19.9	22.0 – 22.8
38	3d ⁹ 4s ² 4p ⁵ 5f	113	12.2 – 12.5	14.7 – 15.1	17.4 – 17.8	20.2 – 20.7	23.1 – 23.7
39	3d ⁹ 4s ² 4p ⁵ 5g	119°	12.2 – 12.5	14.8 – 15.2	17.5 – 18.0	20.4 – 20.9	23.4 – 24.0

Table 2. Energies (Ryd) for the lowest 31 levels of Sr IV.

Index	Configuration	Level	NIST	GRASP2a	GRASP2b	GRASP3	FAC1	FAC2	FAC3
1	4s ² 4p ⁵	² P _{3/2} ^o	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	4s ² 4p ⁵	² P _{1/2} ^o	0.08865	0.08580	0.08396	0.08510	0.09128	0.08801	0.08812
3	4s4p ⁶	² S _{1/2}	1.37149	1.34619	1.42587	1.44410	1.46260	1.47424	1.46391
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	1.70553	1.65949	1.72016	1.75580	1.77666	1.79194	1.78496
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	1.70590	1.66119	1.72216	1.75740	1.77668	1.79181	1.78502
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	1.71340	1.66959	1.73051	1.76560	1.78486	1.79993	1.79324
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	1.72339	1.67979	1.74053	1.77570	1.79724	1.81238	1.80563
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	1.79574	1.76139	1.82292	1.85900	1.86623	1.88674	1.88277
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	1.82563	1.79409	1.85556	1.89120	1.89699	1.91794	1.91435
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	1.82736	1.81929	1.88463	1.92440	1.92252	1.94584	1.94315
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	1.85301	1.81889	1.87983	1.91360	1.92612	1.94461	1.94092
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	1.86062	1.82929	1.89037	1.92180	1.93655	1.95160	1.94816
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	1.86576	1.84949	1.91510	1.95600	1.94719	1.97585	1.97497
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	1.86630	1.85239	1.91773	1.95620	1.95263	1.97723	1.97562
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	1.88199	1.87389	1.93923	1.97160	1.97384	1.99236	1.99005
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	1.89068	1.87849	1.94197	1.98050	1.97339	1.99994	1.99863
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	1.90398	1.88809	1.95321	1.98860	1.98671	2.00978	2.00848
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.90647	1.89589	1.96084	1.99670	1.99774	2.01961	2.01784
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	1.93164	1.92249	1.98705	2.02010	2.01960	2.04090	2.03959
20	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	1.95873	1.95119	2.01635	2.05440	2.04978	2.07643	2.07603
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	1.96093	1.95249	2.01370	2.04620	2.04955	2.06689	2.06394
22	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	1.96094	1.95399	2.01703	2.05040	2.05268	2.07196	2.06975
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	2.05829	2.07879	2.14641	2.18590	2.16103	2.19311	2.19528
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	2.07858	2.09719	2.16432	2.20420	2.17931	2.21245	2.21470
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	2.20683	2.26209	2.33287	2.29400	2.33357	2.30394	2.30686
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	2.23930	2.28919	2.35916	2.31430	2.36409	2.32614	2.32847
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	2.29991	2.42829	2.49870	2.41760	2.47141	2.45258	2.45337
28	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	2.30762	2.45749	2.52825	2.44470	2.50013	2.47961	2.48054
29	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	2.32210	2.48659	2.55533	2.45350	2.52189	2.49083	2.48627
30	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	2.34510	2.54509	2.62876	2.51540	2.57417	2.54771	2.52024
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	2.40740	2.56949	2.63736	2.52380	2.61111	2.56987	2.56654

NIST: http://physics.nist.gov/PhysRefData/ASD/levels_form.html

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC1: present calculations from the FAC code with 470 levels

FAC2: present calculations from the FAC code with 3990 levels

FAC3: present calculations from the FAC code with 12,137 levels

Table 3. Energies (Ryd) for the lowest 31 levels of Y V.

Index	Configuration	Level	NIST	GRASP2a	GRASP2b	GRASP3	FAC1	FAC2	FAC3
1	4s ² 4p ⁵	² P _{3/2} ^o	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	4s ² 4p ⁵	² P _{1/2} ^o	0.11354	0.11070	0.10869	0.11016	0.11584	0.11221	0.11242
3	4s4p ⁶	² S _{1/2}	1.55777	1.53529	1.63922	1.63952	1.66378	1.68518	1.67802
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	1.99039	1.95439	2.04350	2.03778	2.08415	2.09809	2.09281
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}		1.95489	2.04279	2.03768	2.08521	2.09935	2.09386
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	1.99909	1.96479	2.05347	2.04756	2.09388	2.10777	2.10266
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}		1.97829	2.06682	2.06129	2.10923	2.12333	2.11821
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}		2.06969	2.15829	2.14949	2.18962	2.20684	2.20336
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}		2.10979	2.19842	2.18916	2.22817	2.24589	2.24292
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	2.12979	2.13549	2.22760	2.22078	2.25419	2.27477	2.27360
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	2.16587	2.14179	2.22998	2.21897	2.26452	2.27915	2.27610
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	2.17077	2.15269	2.24117	2.22643	2.27452	2.28432	2.28175
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	2.17700	2.17569	2.26792	2.26118	2.28892	2.31553	2.31599
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	2.17913	2.17809	2.27008	2.26109	2.29418	2.31587	2.31561
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	2.19568	2.19999	2.29201	2.27849	2.31558	2.33235	2.33154
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}		2.20779	2.29778	2.28741	2.32020	2.34148	2.34040
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	2.22633	2.22529	2.31702	2.30421	2.33938	2.35905	2.35960
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	2.22907	2.23199	2.32365	2.31417	2.34982	2.37023	2.37017
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	2.25868	2.26259	2.35390	2.34111	2.37687	2.39602	2.39615
20	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}		2.28759	2.37680	2.36325	2.40286	2.41598	2.41363
21	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}		2.29049	2.38026	2.36683	2.40545	2.42076	2.41929
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	2.29096	2.29989	2.39033	2.37964	2.41329	2.43587	2.43625
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	2.39830	2.43559	2.52895	2.51624	2.53536	2.56282	2.56557
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}		2.46109	2.55404	2.54187	2.56126	2.58950	2.59244
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	2.56288	2.63429	2.73026	2.63982	2.72567	2.68386	2.68757
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	2.60623	2.67089	2.76600	2.67046	2.76567	2.71562	2.71925
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	2.70710	2.85948	2.95379	2.80873	2.92552	2.88542	2.82960
28	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	2.75807	2.88958	2.98556	2.84194	2.95321	2.91641	2.91254
29	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	2.73581	2.92628	3.01877	2.86031	2.98561	2.94256	2.93524
30	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	2.68791	2.94618	3.04846	2.93707	3.00536	2.99160	2.99604
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	2.84354	3.02998	3.12163	2.95577	3.09521	3.03878	3.03076

NIST: http://physics.nist.gov/PhysRefData/ASD/levels_form.html

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC1: present calculations from the FAC code with 470 levels

FAC2: present calculations from the FAC code with 3990 levels

FAC3: present calculations from the FAC code with 12,137 levels

Table 4. Energies (Ryd) for the lowest 31 levels of Zr VI.

Index	Configuration	Level	NIST	GRASP2a	GRASP2b	GRASP3	FAC1	FAC2	FAC3
1	4s ² 4p ⁵	² P _{3/2} ^o	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	4s ² 4p ⁵	² P _{1/2} ^o	0.14218	0.13790	0.13719	0.13852	0.14422	0.14027	0.14058
3	4s4p ⁶	² S _{1/2}	1.74572	1.72609	1.85015	1.84426	1.86689	1.89504	1.89028
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	2.26849	2.22219	2.35172	2.32398	2.38141	2.39190	2.38799
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	2.27383	2.22329	2.35284	2.32581	2.38421	2.39499	2.39083
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	2.27834	2.23379	2.36336	2.33532	2.39269	2.40310	2.39940
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	2.30038	2.25129	2.38079	2.35322	2.41187	2.42263	2.41897
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	2.37892	2.34759	2.47839	2.44657	2.49998	2.51192	2.50911
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	2.42527	2.39529	2.52620	2.49375	2.54604	2.55851	2.55634
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	2.42652	2.42659	2.55677	2.53249	2.57469	2.58911	2.58904
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	2.47293	2.44719	2.56717	2.52571	2.59208	2.60078	2.59853
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	2.47222	2.43629	2.57785	2.53730	2.60024	2.60221	2.60070
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	2.47949	2.47339	2.60489	2.57427	2.61720	2.63754	2.63878
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	2.48624	2.47679	2.60774	2.57428	2.62344	2.63850	2.63901
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	2.50294	2.49999	2.63063	2.59450	2.64605	2.65788	2.65815
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	2.52597	2.50679	2.63844	2.60400	2.65367	2.66757	2.66690
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	2.54009	2.53399	2.66563	2.62709	2.67898	2.69048	2.69186
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	2.54663	2.54399	2.67479	2.64152	2.69248	2.70698	2.70798
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	2.57992	2.57649	2.70785	2.67242	2.72290	2.73680	2.73795
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	2.60324	2.59749	2.73076	2.69307	2.74738	2.75628	2.75561
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	2.60990	2.59989	2.72800	2.69048	2.74599	2.75289	2.75131
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	2.61664	2.61839	2.75028	2.71456	2.76475	2.77958	2.78065
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	2.73025	2.76328	2.89566	2.85774	2.89540	2.91460	2.91797
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	2.76587	2.79618	2.92883	2.89147	2.92958	2.94951	2.95304
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	2.91002	2.98018	3.11146	2.99315	3.10213	3.04750	3.05187
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	2.96565	3.02848	3.15949	3.03607	3.15469	3.09217	3.09649
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	3.09541	3.24168	3.38303	3.21302	3.35248	3.29129	3.29429
28	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	3.04998	3.26788	3.40688	3.24837	3.36795	3.32439	3.32751
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	3.15617	3.31168	3.46308	3.33776	3.42794	3.39881	3.40174
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	3.13216	3.32448	3.45499	3.27798	3.42019	3.35821	3.35799
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	3.26390	3.43938	3.58231	3.39676	3.55405	3.48125	3.46307

NIST: http://physics.nist.gov/PhysRefData/ASD/levels_form.html

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC1: present calculations from the FAC code with 470

FAC2: present calculations from the FAC code with 3990

FAC3: present calculations from the FAC code with 12,137 levels

Table 5. Energies (Ryd) for the lowest 31 levels of Nb VII.

Index	Configuration	Level	NIST	GRASP2a	GRASP2b	GRASP3	FAC1	FAC2	FAC3
1	4s ² 4p ⁵	² P _{3/2} ^o	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	4s ² 4p ⁵	² P _{1/2} ^o	0.17488	0.17060	0.16977	0.17094	0.17670	0.17247	0.17287
3	4s4p ⁶	² S _{1/2}	1.93645	1.92489	2.06099	2.04997	2.07253	2.10509	2.10205
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	2.55304	2.51099	2.65085	2.60419	2.67207	2.67789	2.67506
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}		2.51449	2.65439	2.60858	2.67725	2.68346	2.68036
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	2.54232	2.52429	2.66410	2.61698	2.68483	2.69044	2.68786
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}		2.54649	2.68634	2.63977	2.70860	2.71469	2.71220
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}		2.64749	2.78813	2.73659	2.80212	2.80786	2.80566
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}		2.70258	2.84334	2.79085	2.85515	2.86133	2.85990
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	2.72076	2.73708	2.87723	2.82506	2.88891	2.89561	2.89618
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	2.77699	2.76398	2.89644	2.84123	2.91376	2.91545	2.91394
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	2.76368	2.75578	2.90454	2.84059	2.91775	2.91044	2.90993
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	2.77662	2.78998	2.93113	2.87934	2.93694	2.94914	2.95076
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	2.79056	2.79538	2.93614	2.88158	2.94594	2.95299	2.95383
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	2.80736	2.82038	2.96094	2.90529	2.97054	2.97584	2.97676
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}		2.82938	2.97053	2.91550	2.98041	2.98627	2.98598
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	2.84901	2.86288	3.00406	2.94241	3.01047	3.01205	3.01387
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	2.86238	2.87828	3.01898	2.96455	3.03036	3.03694	3.03854
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	2.89898	2.91348	3.05449	2.99912	3.06353	3.07048	3.07224
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}		2.93298	3.07359	3.01492	3.08355	3.08488	3.08490
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}		2.93218	3.07265	3.01464	3.08432	3.08417	3.08334
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	2.93916	2.96018	3.10151	3.04360	3.10941	3.11496	3.11651
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	3.05794	3.11078	3.25236	3.19222	3.24718	3.25650	3.26021
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}		3.15278	3.29456	3.23499	3.29042	3.30049	3.30435
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	3.25314	3.34238	3.48307	3.34059	3.47023	3.40275	3.40749
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	3.32687	3.40598	3.54658	3.39929	3.53861	3.46374	3.46846
27	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	3.40216	3.64738	3.80087	3.63579	3.75984	3.71226	3.71659
28	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	3.47197	3.65598	3.79497	3.59877	3.76239	3.67961	3.68365
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	3.54432	3.72368	3.87262	3.72157	3.84506	3.78908	3.79379
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	3.51492	3.73168	3.87813	3.67645	3.83604	3.75806	3.75930
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	3.67477	3.87958	4.02827	3.82167	3.99813	3.90759	3.90984

NIST: http://physics.nist.gov/PhysRefData/ASD/levels_form.html

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC1: present calculations from the FAC code with 470 levels

FAC2: present calculations from the FAC code with 3990 levels

FAC3: present calculations from the FAC code with 12,137 levels

Table 6. Energies (Ryd) for the lowest 31 levels of Mo VIII.

Index	Configuration	Level	NIST	GRASP2a	GRASP2b	GRASP3	FAC1	FAC2	FAC3
1	4s ² 4p ⁵	² P _{3/2} ^o	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	4s ² 4p ⁵	² P _{1/2} ^o	0.21209	0.20770	0.20676	0.20776	0.21363	0.20913	0.20962
3	4s4p ⁶	² S _{1/2}	2.13082	2.12679	2.27306	2.25774	2.28111	2.31642	2.31460
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	2.81307	2.79438	2.94319	2.88062	2.95802	2.95864	2.95659
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}		2.80088	2.94980	2.88823	2.96622	2.96738	2.96505
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	2.82436	2.80908	2.95788	2.89461	2.97206	2.97229	2.97051
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}		2.83678	2.98561	2.92291	3.00109	3.00186	3.00021
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}		2.94108	3.09038	3.02231	3.09862	3.09795	3.09621
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}		3.00278	3.15221	3.08273	3.15778	3.15727	3.15638
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	3.01450	3.04338	3.19233	3.12243	3.19970	3.19842	3.19928
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	3.05879	3.07138	3.22305	3.13829	3.22889	3.21173	3.21195
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	3.07954	3.10018	3.22072	3.14797	3.23226	3.22651	3.22557
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	3.07039	3.07388	3.24975	3.17990	3.25085	3.25444	3.25614
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	3.09398	3.10968	3.25906	3.18700	3.26494	3.26378	3.26468
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	3.11072	3.13738	3.28654	3.21432	3.29200	3.29015	3.29142
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}		3.14868	3.29824	3.22612	3.30440	3.30240	3.30236
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	3.15494	3.18568	3.33528	3.25358	3.33650	3.32775	3.32973
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	3.17879	3.20998	3.35937	3.28684	3.36623	3.36437	3.36621
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	3.21812	3.24758	3.39715	3.32473	3.40180	3.40120	3.40326
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}		3.26258	3.41187	3.33549	3.41688	3.41039	3.41091
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}		3.26488	3.41404	3.33888	3.42098	3.41371	3.41344
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	3.26061	3.29768	3.44736	3.37036	3.45040	3.44632	3.44811
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	3.38391	3.45298	3.60277	3.52373	3.59423	3.59342	3.59720
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}		3.50498	3.65493	3.57645	3.64736	3.64733	3.65125
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	3.59536	3.70008	3.84920	3.68624	3.83405	3.75434	3.75919
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	3.68975	3.78268	3.93173	3.76445	3.92182	3.83531	3.84018
27	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	3.74997	4.02958	4.18120	4.01094	4.14037	4.08705	4.09204
28	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	3.84153	4.04118	4.19501	3.97538	4.16110	4.05783	4.06231
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	3.92728	4.12238	4.28906	4.10027	4.25591	4.17334	4.17883
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	3.88909	4.13578	4.27715	4.06291	4.23931	4.14535	4.14748
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	4.08135	4.31058	4.46526	4.23847	4.43382	4.32532	4.32852

NIST: http://physics.nist.gov/PhysRefData/ASD/levels_form.html

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC1: present calculations from the FAC code with 470 levels

FAC2: present calculations from the FAC code with 3990 levels

FAC3: present calculations from the FAC code with 12,137 levels

Table 7. Comparison of radiative rates (A- values, s^{-1}) for E1 transitions among levels of the ground state $4s^2 4p^5$ $^2P_{3/2,1/2}^o$ and $4s4p^6$ and $4s^2 4p^4 4d$ configurations of Sr IV – see Table 2 for level definitions. $a \pm b \equiv a \times 10^{\pm b}$.

Transition		GRASP2a	GRASP2b	GRASP3		FAC2	FAC3	Ratio
I	J	A	A	A	f	A	A	
1	3	1.55+08	3.6342+08	3.5713+08	1.0660-02	4.077+08	4.074+08	2.2-1
1	5	5.27+06	5.9143+06	1.0231+07	6.1860-04	1.199+07	1.181+07	9.4-1
1	6	2.57+06	2.4018+06	2.5331+06	1.0117-04	4.352+06	4.138+06	7.8-1
1	7	1.02+06	8.0619+05	4.1581+05	8.2090-06	1.605+06	1.383+06	4.8-1
1	10	5.83+06	4.4562+06	3.3635+05	5.6538-06	1.857+06	6.461+05	1.9-0
1	11	5.38+07	4.6873+07	8.1160+07	4.1389-03	1.073+08	1.047+08	9.1-1
1	12	5.38+06	6.5981+06	8.0781+06	2.7229-04	1.591+06	3.035+06	9.4-1
1	13	1.60+08	1.4338+08	2.5878+08	4.2103-03	2.979+08	3.068+08	7.9-1
1	14	2.19+08	1.6215+08	1.7587+08	5.7215-03	2.437+08	2.049+08	8.7-1
1	15	2.01+08	1.4387+08	2.1917+08	7.0193-03	1.689+08	1.644+08	9.4-1
1	17	7.00+07	4.9727+07	7.6048+07	3.5911-03	6.909+07	5.897+07	8.1-1
1	18	1.00+08	7.4910+07	6.0688+04	1.8950-06	1.481+05	8.054+05	4.2-0
1	19	3.43+08	2.2873+08	2.3311+08	1.0667-02	1.659+08	1.552+08	9.1-1
1	20	1.57+08	1.2299+08	1.6340+08	7.2302-03	1.331+08	1.117+08	9.7-1
1	23	1.59+08	1.3933+08	2.3389+08	9.1410-03	3.224+08	2.939+08	8.1-1
1	25	6.12+08	4.7105+08	1.9286+09	4.5624-02	1.336+09	2.203+09	9.7-1
1	26	3.76+08	2.5017+08	1.5860+09	5.5298-02	1.082+09	1.729+09	1.0-0
1	27	8.91+10	6.9511+10	5.7718+10	1.2294-00	6.832+10	6.554+10	9.1-1
1	28	5.15+10	3.8773+10	3.0543+10	3.1811-01	4.191+10	4.402+10	9.0-1
1	29	1.08+11	9.1973+10	5.7973+10	1.7984-00	7.551+10	7.786+10	8.8-1
1	30	5.39+10	5.4270+10	3.4522+10	3.3963-01	3.371+10	2.042+10	8.1-1
1	31	4.98+09	4.5917+09	2.5073+09	4.9008-02	2.771+09	2.378+09	8.3-1
2	3	7.79+07	1.7135+08	1.7377+08	1.1714-02	1.989+08	1.977+08	2.0-1
2	6	4.86+04	2.3776+04	2.9543+05	2.6047-05	3.689+05	4.498+05	1.3-0
2	7	1.33+06	9.7317+05	3.4896+05	1.5200-05	8.247+05	6.745+05	4.6-1
2	10	3.05+07	2.5164+07	3.7542+06	1.3816-04	1.106+07	8.324+06	4.9-1
2	12	2.16+07	2.2836+07	3.1660+07	2.3367-03	3.526+07	3.536+07	9.7-1
2	13	4.30+06	6.4777+06	3.0353+06	1.0796-04	7.175+06	7.375+06	1.8-1
2	14	1.59+07	1.4550+07	7.7999+05	5.5470-05	8.083+05	6.851+05	1.3-0
2	15	2.61+08	1.8430+08	2.5448+08	1.7804-02	2.484+08	2.282+08	9.1-1
2	18	5.65+07	3.7116+07	3.0459+07	2.0753-03	1.150+07	1.228+07	9.3-1
2	25	1.99+09	1.5167+09	3.5455+08	1.8092-02	3.779+08	4.531+08	6.5-1
2	27	2.60+09	1.7449+09	6.5874+08	3.0148-02	1.305+09	7.921+08	1.1-0
2	28	4.16+10	3.3517+10	2.7800+10	6.2157-01	2.895+10	2.360+10	9.3-1
2	30	5.37+10	4.5666+10	3.7795+10	7.9664-01	4.680+10	3.969+10	8.3-1
2	31	1.01+11	8.5572+10	7.0119+10	2.9356-00	8.032+10	7.831+10	8.8-1

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

FAC2: present calculations from the FAX code with 3990 levels

FAC3: present calculations from the FAX code with 12,137 levels

Ratio: ratio of velocity and length forms of A- values

Table 8. Comparison of radiative rates (A- values, s^{-1}) for E1 transitions among levels of the ground state $4s^2 4p^5$ $^2P_{3/2,1/2}^o$ and $4s4p^6$ and $4s^2 4p^4 4d$ configurations of Y V – see Table 3 for level definitions. $a \pm b \equiv a \times 10^{\pm b}$.

Transition		GRASP2a	GRASP2b		GRASP3	
I	J	A	A	A	f	Ratio
1	3	3.41+08	7.4178+08	6.4885+08	1.5026-02	4.0-1
1	4	8.49+06	1.0049+07	1.4695+07	6.6085-04	9.5-1
1	6	5.17+06	5.0984+06	5.7124+06	1.6963-04	9.3-1
1	7	2.69+06	2.3091+06	1.9727+06	2.8901-05	8.8-1
1	10	1.10+07	9.1719+06	2.4808+06	3.1312-05	1.4-0
1	11	9.04+07	8.3561+07	1.3428+08	5.0927-03	9.5-1
1	12	2.44+06	5.2851+06	2.4683+06	6.1990-05	1.0-0
1	13	2.90+08	2.7110+08	3.9343+08	4.7899-03	8.1-1
1	14	3.73+08	2.9292+08	4.1741+08	1.0164-02	9.5-1
1	15	2.77+08	2.0450+08	2.3712+08	5.6861-03	9.3-1
1	17	1.10+08	7.8261+07	1.2373+08	4.3518-03	8.4-1
1	18	8.38+07	6.4620+07	6.7013+06	1.5578-04	1.2-0
1	19	3.66+08	2.4426+08	2.4821+08	8.4570-03	9.6-1
1	22	1.49+08	1.1934+08	2.2968+08	7.5744-03	1.0-0
1	23	2.34+08	2.1489+08	3.3501+08	9.8810-03	8.3-1
1	25	1.06+09	8.6167+08	3.1288+09	5.5895-02	9.8-1
1	26	5.28+07	1.8626+07	1.4890+09	3.8992-02	1.1-0
1	27	1.27+11	1.0138+11	1.0669+11	1.6837-00	9.2-1
1	28	1.07+11	8.2858+10	6.8148+10	5.2522-01	9.0-1
1	29	1.55+11	1.3485+11	1.2220+11	2.7893-00	9.0-1
1	30	3.70+10	4.5026+10	5.8584+10	4.2274-01	8.1-1
1	31	6.68+09	6.2932+09	4.2526+09	6.0599-02	8.7-1
2	3	1.59+08	3.3294+08	3.0194+08	1.6071-02	3.7-1
2	6	1.47+05	1.0055+04	7.9784+04	5.2924-06	1.1-0
2	7	3.11+06	2.4823+06	1.7391+06	5.6874-05	1.0-0
2	10	5.58+07	4.8736+07	2.7075+07	7.5666-04	1.0-0
2	12	2.89+07	3.3965+07	4.0470+07	2.2499-03	1.0-0
2	13	1.30+07	1.7692+07	1.1362+07	3.0570-04	5.0-1
2	14	2.24+07	2.1717+07	2.7072+06	1.4570-04	1.5-0
2	15	3.20+08	2.2841+08	3.2991+08	1.7471-02	9.7-1
2	18	2.86+07	1.6216+07	1.7387+07	8.9120-04	8.7-1
2	25	1.92+09	1.4732+09	5.6428+08	2.1956-02	7.0-1
2	27	3.32+09	2.2497+09	2.3159+09	7.9184-02	9.9-1
2	28	2.85+10	2.6514+10	4.1111+10	6.8582-01	9.5-1
2	30	1.03+11	8.4428+10	3.9796+10	6.1996-01	8.6-1
2	31	1.46+11	1.2577+11	1.2065+11	3.7097-00	9.0-1

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Ratio: ratio of velocity and length forms of A -values

Table 9. Comparison of radiative rates (A- values, s^{-1}) for E1 transitions among levels of the ground state $4s^24p^5$ $^2P_{3/2,1/2}^o$ and $4s4p^6$ and $4s^24p^44d$ configurations of Zr VI – see Table 4 for level definitions. $a \pm b \equiv a \times 10^{\pm b}$.

Transition		GRASP2a	GRASP2b	GRASP3		
I	J	A	A	A	f	Ratio
1	3	5.30+08	1.2340+09	1.0518+09	1.9249-02	4.4-1
1	4	1.17+07	1.5391+07	2.0308+07	7.0217-04	9.4-1
1	6	7.76+06	9.2931+06	1.1017+07	2.5149-04	9.8-1
1	7	4.75+06	5.3458+06	5.6982+06	6.4052-05	9.8-1
1	10	1.28+07	1.4776+07	2.1200+08	6.1728-03	9.6-1
1	11	1.41+08	1.4199+08	1.0789+07	1.0527-04	1.4-0
1	12	3.35+05	1.0270+06	5.1806+05	1.0018-05	9.2-1
1	13	4.67+08	4.7004+08	5.9759+08	5.6133-03	8.0-1
1	14	5.50+08	4.8841+08	7.0038+08	1.3157-02	9.8-1
1	15	3.37+08	2.5187+08	2.5390+08	4.6958-03	9.1-1
1	17	1.60+08	1.1567+08	1.5603+08	4.2219-03	8.3-1
1	18	6.97+07	6.2901+07	1.7608+07	3.1416-04	1.3-0
1	19	3.82+08	2.5563+08	2.6359+08	6.8923-03	9.8-1
1	22	1.96+08	1.4639+08	3.0306+08	7.6802-03	1.0-0
1	23	3.24+08	3.1381+08	3.9608+08	9.0568-03	8.2-1
1	25	1.68+09	1.4350+09	4.0018+09	5.5609-02	9.9-1
1	26	3.16+02	2.1868+07	2.1104+09	4.2754-02	1.1-0
1	27	1.56+11	1.3479+11	1.2527+11	1.5107-00	9.3-1
1	28	1.63+11	1.5331+11	9.7116+10	5.7290-01	9.0-1
1	29	1.91+11	1.0623+10	6.3978+10	3.5747-01	8.0-1
1	30	1.29+10	1.7896+11	1.6154+11	2.8075-00	9.1-1
1	31	7.17+09	7.6240+09	7.1045+09	7.6658-02	8.8-1
2	3	2.40+08	5.3588+08	4.7253+08	2.0219-02	4.1-1
2	6	3.21+05	1.0080+03	1.2890-00	6.6505-11	1.2+3
2	7	4.55+06	4.9856+06	4.8266+06	1.2251-04	1.1-0
2	10	6.32+07	7.2178+07	6.0598+07	1.3238-03	1.1-0
2	12	3.56+07	4.7038+07	5.1666+07	2.2356-03	1.1-0
2	13	2.37+07	3.6522+07	2.6970+07	5.6593-04	6.0-1
2	14	1.58+07	2.0358+07	3.2332+06	1.3569-04	1.7-0
2	15	3.78+08	2.7949+08	4.0027+08	1.6523-02	9.9-1
2	18	2.06+07	8.4120+06	1.1180+07	4.4433-04	7.5-1
2	25	2.20+09	1.6511+09	6.9689+08	2.1293-02	7.0-1
2	27	3.20+09	2.4759+09	2.5940+09	6.8328-02	1.0-0
2	28	8.16+09	3.4364+09	3.9101+10	5.0334-01	9.8-1
2	29	1.52+11	1.4005+11	9.6829+10	1.1778-00	8.6-1
2	31	1.80+11	1.6739+11	1.5364+11	3.6034-00	9.1-1

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Ratio: ratio of velocity and length forms of A- values

Table 10. Comparison of radiative rates (A- values, s^{-1}) for E1 transitions among levels of the ground state $4s^2 4p^5$ $^2P_{3/2,1/2}^o$ and $4s 4p^6$ and $4s^2 4p^4 4d$ configurations of Nb VII – see Table 5 for level definitions. $a \pm b \equiv a \times 10^{\pm b}$.

Transition		GRASP2a	GRASP2b	GRASP3		
I	J	A	A	A	f	Ratio
1	3	8.66+08	1.8359+09	1.5435+09	2.2863-02	4.5-1
1	4	1.68+07	2.1932+07	2.6950+07	7.4210-04	9.3-1
1	6	1.34+07	1.5424+07	1.8777+07	3.4134-04	1.0-0
1	7	1.02+07	1.1016+07	1.2926+07	1.1546-04	9.9-1
1	10	1.92+07	2.0712+07	2.0504+07	1.5992-04	1.4-0
1	11	2.29+08	2.3196+08	3.2927+08	7.6169-03	9.5-1
1	12	7.74+06	3.7905+06	1.9836+07	3.0605-04	9.6-1
1	13	7.65+08	7.6492+08	8.9955+08	6.7540-03	7.9-1
1	14	8.57+08	7.5394+08	1.0257+09	1.5378-02	9.8-1
1	15	3.83+08	2.8801+08	2.9256+08	4.3151-03	8.9-1
1	17	2.27+08	1.6263+08	1.9368+08	4.1775-03	8.1-1
1	18	7.40+07	6.7028+07	3.0557+07	4.3286-04	1.3-0
1	19	4.16+08	2.7767+08	3.0418+08	6.3152-03	9.9-1
1	22	2.52+08	1.9994+08	4.1267+08	8.3189-03	1.0-0
1	23	4.50+08	4.3792+08	4.8703+08	8.9250-03	8.1-1
1	25	2.62+09	2.2474+09	5.3405+09	5.9578-02	9.9-1
1	26	8.11+07	1.6709+08	2.9244+09	4.7261-02	1.0-0
1	27	1.98+11	2.0079+11	1.4062+11	6.6216-01	8.9-1
1	28	2.18+11	1.6914+11	1.5224+11	1.4635-00	9.3-1
1	29	2.41+11	2.2363+11	5.2042+10	2.3390-01	7.8-1
1	30	1.84+07	2.3751+06	1.9979+11	2.7603-00	9.1-1
1	31	8.15+09	8.5737+09	8.3648+09	7.1302-02	8.8-1
2	3	3.77+08	7.7571+08	6.7475+08	2.3791-02	4.2-1
2	6	8.18+05	5.8651+04	1.2640+05	5.2601-06	1.4-0
2	7	8.45+06	8.7486+06	9.8501+06	2.0119-04	1.2-0
2	10	8.66+07	9.3367+07	9.1692+07	1.6205-03	1.2-0
2	12	4.28+07	6.0657+07	6.3245+07	2.2095-03	1.1-0
2	13	4.60+07	6.5045+07	5.0617+07	8.5904-04	6.3-1
2	14	8.79+06	1.1772+07	1.5539+06	5.2657-05	2.2-0
2	15	4.56+08	3.4446+08	4.7877+08	1.5944-02	1.0-0
2	18	1.54+07	5.5585+06	9.2858+06	2.9626-04	6.6-1
2	25	2.61+09	2.0128+09	9.8756+08	2.4475-02	7.3-1
2	27	3.32+09	1.4226+09	2.9884+10	3.0990-01	1.0-0
2	28	3.20+08	2.4534+09	2.7930+09	5.9185-02	1.0-0
2	29	1.99+11	1.7491+11	1.3456+11	1.3287-00	8.7-1
2	31	2.28+11	2.0973+11	1.9008+11	3.5510-00	9.1-1

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Ratio: ratio of velocity and length forms of A- values

Table 11. Comparison of radiative rates (A- values, s^{-1}) for E1 transitions among levels of the ground state $4s^2 4p^5$ $^2P_{3/2,1/2}^o$ and $4s 4p^6$ and $4s^2 4p^4 4d$ configurations of Mo VIII – see Table 6 for level definitions. $a \pm b \equiv a \times 10^{\pm b}$.

Transition		GRASP2a	GRASP2b	GRASP3		
I	J	A	A	A	f	Ratio
1	3	1.29+09	2.5432+09	2.1245+09	2.5943-02	4.6-1
1	4	2.28+07	2.9581+07	3.4543+07	7.7738-04	9.2-1
1	6	2.13+07	2.3934+07	2.9526+07	4.3870-04	1.0-0
1	7	2.00+07	2.0959+07	2.5720+07	1.8739-04	9.8-1
1	10	2.51+07	2.6107+07	2.9036+07	1.8539-04	1.3-0
1	11	3.63+08	4.5188+07	8.3700+07	1.0580-03	9.5-1
1	12	6.58+07	3.6663+08	5.0141+08	9.4488-03	9.5-1
1	13	1.19+09	1.1856+09	1.3282+09	8.1761-03	7.8-1
1	14	1.22+09	1.0656+09	1.3902+09	1.7040-02	9.7-1
1	15	4.32+08	3.2722+08	3.6056+08	4.3446-03	8.8-1
1	17	3.09+08	2.2203+08	2.4601+08	4.3398-03	8.0-1
1	18	8.29+07	7.5243+07	4.6619+07	5.3723-04	1.3-0
1	19	4.74+08	3.2086+08	3.8150+08	6.4450-03	9.9-1
1	22	3.42+08	2.8357+08	5.6353+08	9.2641-03	9.9-1
1	23	6.00+08	5.8754+08	6.0305+08	9.0695-03	8.1-1
1	25	3.93+09	3.3730+09	7.2030+09	6.5992-02	9.8-1
1	26	3.18+08	4.5232+08	4.0447+09	5.3300-02	1.0-0
1	27	2.56+11	2.3491+11	1.9071+11	7.3791-01	8.8-1
1	28	2.39+11	2.0401+11	1.8003+11	1.4182-00	9.3-1
1	29	2.91+11	3.3603+09	3.4261+10	1.2685-01	7.4-1
1	30	4.80+09	2.6848+11	2.3757+11	2.6875-00	9.0-1
1	31	8.74+09	9.1757+09	9.3027+09	6.4468-02	8.8-1
2	3	5.44+08	1.0480+09	9.0658+08	2.6857-02	4.2-1
2	6	1.75+06	2.7579+05	6.0372+05	2.0822-05	1.2-0
2	7	1.40+07	1.3921+07	1.7026+07	2.8753-04	1.2-0
2	10	1.06+08	1.1101+08	1.1742+08	1.7208-03	1.2-0
2	11	4.76+07	7.2300+07	7.4734+07	2.1668-03	1.1-0
2	13	7.85+07	1.0526+08	8.3988+07	1.1837-03	6.4-1
2	14	1.99+06	3.0099+06	7.7973+04	2.1873-06	1.0+1
2	15	5.42+08	4.1898+08	5.6237+08	1.5490-02	1.0-0
2	18	1.43+07	4.9598+06	9.8751+06	2.5935-04	6.3-1
2	25	3.26+09	2.5724+09	1.4586+09	3.0014-02	7.5-1
2	27	5.79+09	7.7879+09	1.7297+10	1.4887-01	1.1-0
2	28	3.16+09	2.2314+09	2.7063+09	4.7470-02	1.0-0
2	29	2.32+11	2.0141+11	1.7509+11	1.4386-00	8.7-1
2	31	2.76+11	2.5240+11	2.2654+11	3.4718-00	9.1-1

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Ratio: ratio of velocity and length forms of A- values

Table 12. Comparison of lifetimes (τ , s) for the lowest 31 levels of Sr IV. $a \pm b \equiv a \times 10^{\pm b}$.

Index	Configuration	Level	GRASP2a	GRASP2b	GRASP3	GRASP2b (dominant A- values, s ⁻¹)
1	4s ² 4p ⁵	² P _{3/2} ^o	.....	.....	.....	.....
2	4s ² 4p ⁵	² P _{1/2} ^o	6.18-02	7.112-02	6.836-02	1 - 2 M1 = 1.405+01
3	4s4p ⁶	² S _{1/2}	1.71-09	1.870-09	1.884-09	1 - 3 E1 = 3.634+08, 2 - 3, E1 = 1.714+08
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	1.90-01	1.484-01	1.193-01	1 - 4 M2 = 6.740+00
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	1.17-07	1.691-07	9.774-08	1 - 5 E1 = 5.914+06
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	3.64-07	4.123-07	3.535-07	1 - 6 E1 = 2.402+06
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	1.39-06	5.620-07	1.308-06	1 - 7 E1 = 8.062+05, 2 - 7, E1 = 9.732+05
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	7.45-01	7.697-01	7.896-01	4 - 8 M1 = 1.287+00
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	1.73-00	2.984-01	2.957-01	4 - 9 M1 = 1.231+00, 8 - 9, M1 = 1.374+00
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	1.03-06	3.376-08	2.445-07	2 - 10 E1 = 2.516+07
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	1.59-08	2.133-08	1.232-08	1 - 11 E1 = 4.687+07
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	2.01-07	3.397-08	2.516-08	1 - 12 E1 = 6.598+06, 2 - 12, E1 = 2.284+07
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	4.60-09	6.673-09	3.819-09	1 - 13 E1 = 1.434+08
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	5.75-09	5.659-09	5.661-09	1 - 14 E1 = 1.622+08
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	5.28-09	3.047-09	2.111-09	1 - 15 E1 = 1.439+08, 2 - 15, E1 = 1.843+08
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	8.43-01	7.657-02	7.731-02	4 - 16 M1 = 5.728+00, 8 - 16, M1 = 3.032+00
17	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	1.71-08	2.011-08	1.315-08	1 - 17 E1 = 4.973+07
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.59-08	8.926-09	3.277-08	1 - 18 E1 = 7.491+07, 2 - 18, E1 = 3.712+07
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	3.88-09	4.372-09	4.290-09	1 - 19 E1 = 2.287+08
20	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	1.05-08	8.131-09	6.120-09	1 - 20 E1 = 1.230+08
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	7.11-01	5.270-02	5.642-02	8 - 21 M1 = 1.501+01
22	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	1.66-00	6.495-02	6.780-02	9 - 22 M1 = 6.240+00
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	5.32-09	7.177-09	4.276-09	1 - 23 E1 = 1.393+08
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	3.83-00	2.309-02	2.357-02	4 - 24 M1 = 1.547+01, 8 - 24, M1 = 1.351+01
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	1.93-09	5.031-10	4.380-10	1 - 25 E1 = 4.710+08, 2 - 25, E1 = 1.517+09
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	3.04-09	3.997-09	6.305-10	1 - 26 E1 = 2.502+08
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	1.17-11	1.403-11	1.713-11	1 - 27 E1 = 6.951+10
28	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	1.82-11	1.383-11	1.714-11	1 - 28 E1 = 3.877+10, 2 - 28, E1 = 3.352+10
29	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	8.37-12	1.087-11	1.725-11	1 - 29 E1 = 9.197+10
30	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	1.49-11	1.001-11	1.383-11	1 - 30 E1 = 5.427+10, 2 - 30, E1 = 4.567+10
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	8.52-12	1.109-11	1.377-11	2 - 31 E1 = 8.557+10

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Table 13. Comparison of lifetimes (τ , s) for the lowest 31 levels of Y V. $a \pm b \equiv a \times 10^{\pm b}$.

Index	Configuration	Level	GRASP2a	GRASP2b	GRASP3	GRASP2b (dominant A- values, s ⁻¹)
1	4s ² 4p ⁵	² P _{3/2} ^o	.....	.....	.....	.....
2	4s ² 4p ⁵	² P _{1/2} ^o	2.90-02	3.278-02	3.148-02	1 - 2 M1 = 3.047+01
3	4s4p ⁶	² S _{1/2}	9.67-10	9.305-10	1.052-09	1 - 3 E1 = 7.418+08, 2 - 3 E1 = 3.329+08
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	7.37-08	9.951-08	6.805-08	1 - 4 E1 = 1.005+07
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	9.74-02	7.091-02	6.619-02	1 - 5 M2 = 1.410+01
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	1.78-07	1.958-07	1.726-07	1 - 6 E1 = 5.098+06
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	4.53-07	2.087-07	2.694-07	1 - 7 E1 = 2.309+06, 2 - 7 E1 = 2.482+06
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	1.04+02	4.485-01	4.804-01	5 - 8 M1 = 2.219+00
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	7.22-01	1.555-01	1.573-01	1 - 9 M2 = 1.731+00, 5 - 9 M1 = 2.122+00, 8 - 9 M1 = 2.457+00
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	3.28-07	1.727-08	3.383-08	2 - 10 E1 = 4.874+07
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	9.53-09	1.197-08	7.447-09	1 - 11 E1 = 8.356+07
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	5.55-06	2.548-08	2.329-08	2 - 12 E1 = 3.396+07
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	2.66-09	3.463-09	2.470-09	1 - 13 E1 = 2.711+08
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	3.36-09	3.178-09	2.380-09	1 - 14 E1 = 2.929+08
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	3.98-09	2.310-09	1.764-09	1 - 15 E1 = 2.045+08, 2 - 15 E1 = 2.284+08
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	5.50-01	3.952-02	4.055-02	5 - 16 M1 = 1.057+01, 8 - 16 M1 = 6.762+00
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	1.17-08	1.278-08	8.082-09	1 - 17 E1 = 7.826+07
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.90-08	1.237-08	4.151-08	1 - 18 E1 = 6.462+07, 2 - 18 E1 = 1.622+07
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	3.84-09	4.094-09	4.029-09	1 - 19 E1 = 2.443+08
20	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	4.77+01	2.856-02	2.994-02	8 - 20 M1 = 2.795+01
21	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	7.23-01	3.336-02	3.447-02	5 - 21 M1 = 6.539+00, 9 - 21 M1 = 1.134+01
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	1.11-08	8.379-09	4.354-09	1 - 22 E1 = 1.193+08
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	3.62-09	4.654-09	2.985-09	1 - 23 E1 = 2.149+08
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	2.93-00	1.258-02	1.300-02	5 - 24 M1 = 2.711+01, 8 - 24 M1 = 2.758+01
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	1.11-09	4.283-10	2.708-10	1 - 25 E1 = 8.617+08, 2 - 25 E1 = 1.473+09
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	1.70-08	5.369-08	6.716-10	1 - 26 E1 = 1.863+07
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	8.35-12	9.650-12	9.174-12	1 - 27 E1 = 1.014+11
28	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	8.37-12	9.143-12	9.153-12	1 - 28 E1 = 8.286+10, 2 - 28 E1 = 2.651+10
29	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	5.93-12	7.416-12	8.183-12	1 - 29 E1 = 1.349+11
30	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	2.32-11	7.725-12	1.016-11	1 - 30 E1 = 4.503+10, 2 - 30 E1 = 8.443+10
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	6.05-12	7.572-12	8.006-12	2 - 31 E1 = 1.258+11

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Table 14. Comparison of lifetimes (τ , s) for the lowest 31 levels of Zr VI. $a \pm b \equiv a \times 10^{\pm b}$.

Index	Configuration	Level	GRASP2a	GRASP2b	GRASP3	GRASP2b (dominant A- values, s ⁻¹)
1	4s ² 4p ⁵	² P _{3/2} ^o	.....	.....	.....	.....
2	4s ² 4p ⁵	² P _{1/2} ^o	1.47-02	1.630-02	1.583-02	1 - 2 M1 = 6.126+01
3	4s4p ⁶	² S _{1/2}	6.31-10	5.650-10	6.560-10	1 - 3 E1 = 1.234+09, 2 - 3 E1 = 5.359+08
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	5.03-08	6.497-08	4.924-08	1 - 4 E1 = 1.539+07
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	3.59-02	3.966-02	3.951-02	1 - 5 M2 = 2.521+01
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	1.00-07	1.076-07	9.077-08	1 - 6 E1 = 9.293+06
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	1.91-07	9.679-08	9.501-08	1 - 7 E1 = 5.346+06, 2 - 7 E1 = 4.986+06
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	9.02+01	2.876-01	3.117-01	5 - 8 M1 = 3.468+00
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	1.80-01	8.920-02	9.182-02	1 - 9 M2 = 3.848+00, 5 - 9 M1 = 3.250+00, 8 - 9 M1 = 3.943+00
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	1.81-07	1.150-08	4.717-09	2 - 10 E1 = 7.218+07
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	5.83-09	7.043-09	1.401-08	1 - 11 E1 = 1.420+08
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	6.16-08	2.081-08	1.916-08	2 - 12 E1 = 4.704+07
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	1.62-09	1.974-09	1.601-09	1 - 13 E1 = 4.700+08
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	2.21-09	1.966-09	1.421-09	1 - 14 E1 = 4.884+08
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	3.16-09	1.882-09	1.529-09	1 - 15 E1 = 2.519+08, 2 - 15 E1 = 2.795+08
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	4.11-01	2.171-02	2.241-02	5 - 16 M1 = 1.845+01, 8 - 16 M1 = 1.447+01
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	8.09-09	8.645-09	6.409-09	1 - 17 E1 = 1.157+08
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.96-08	1.402-08	3.474-08	1 - 18 E1 = 6.290+07
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	3.69-09	3.912-09	3.794-09	1 - 19 E1 = 2.556+08
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	2.42-01	1.810-02	1.879-02	5 - 20 M1 = 1.393+01, 9 - 20 M1 = 2.029+01
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	9.88+00	1.609-02	1.686-02	8 - 21 M1 = 4.981+01
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	8.90-09	6.831-09	3.300-09	1 - 22 E1 = 1.464+08
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	2.55-09	3.187-09	2.525-09	1 - 23 E1 = 3.138+08
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	2.26-00	7.230-03	7.502-03	5 - 24 M1 = 4.515+01, 8 - 24 M1 = 5.213+01
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	6.89-10	3.240-10	2.128-10	1 - 25 E1 = 1.435+09, 2 - 25 E1 = 1.651+09
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	1.26-04	4.573-08	4.738-10	1 - 26 E1 = 2.187+07
27	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	6.45-12	7.285-12	7.821-12	1 - 27 E1 = 1.348+11
28	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	5.08-12	6.380-12	7.341-12	1 - 28 E1 = 1.533+11
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	1.65-10	6.637-12	6.219-12	2 - 29 E1 = 1.401+11
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	4.60-12	5.588-12	6.190-12	1 - 30 E1 = 1.790+11
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	4.70-12	5.714-12	6.221-12	2 - 31 E1 = 1.674+11

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Table 15. Comparison of lifetimes (τ , s) for the lowest 31 levels of Nb VII. $a \pm b \equiv a \times 10^{\pm b}$.

Index	Configuration	Level	GRASP2a	GRASP2b	GRASP3	GRASP2b (dominant A- values, s ⁻¹)
1	4s ² 4p ⁵	² P _{3/2} ^o	.....	.....	.....	.....
2	4s ² 4p ⁵	² P _{1/2} ^o	7.84-03	8.602-03	8.426-03	1 - 2 M1 = 1.161+02
3	4s4p ⁶	² S _{1/2}	4.48-10	3.829-10	4.508-10	1 - 3 E1 = 1.836+09, 2 - 3 E1 = 7.757+08
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	3.62-08	4.560-08	3.711-08	1 - 4 E1 = 2.193+07
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	3.38+02	2.458-02	2.555-02	1 - 5 M2 = 4.068+01
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	6.18-08	6.459-08	5.290-08	1 - 6 E1 = 1.542+07
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	9.19-08	5.060-08	4.391-08	1 - 7 E1 = 1.102+07, 2 - 7 E1 = 8.749+06
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	1.84-01	1.977-01	2.165-01	5 - 8 M1 = 5.050+00
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	3.86+00	5.568-02	5.843-02	1 - 9 M2 = 7.535+00, 5 - 9 M1 = 4.524+00, 8 - 9 M1 = 5.677+00
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	1.30-07	8.766-09	8.913-09	2 - 10 E1 = 9.337+07
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	3.66-09	4.311-09	3.037-09	1 - 11 E1 = 2.320+08
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	8.98-09	1.552-08	1.204-08	2 - 12 E1 = 6.066+07
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	1.03-09	1.205-09	1.052-09	1 - 13 E1 = 7.649+08
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	1.70-09	1.306-09	9.735-10	1 - 14 E1 = 7.539+08
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	2.55-09	1.581-09	1.296-09	1 - 15 E1 = 2.880+08, 2 - 15 E1 = 3.445+08
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	2.39-01	1.230-02	1.267-02	5 - 16 M1 = 3.116+01, 8 - 16 M1 = 2.958+01
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	5.74-09	6.149-09	5.163-09	1 - 17 E1 = 1.626+08
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.83-08	1.378-08	2.510-08	1 - 18 E1 = 6.703+07
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	3.37-09	3.601-09	3.288-09	1 - 19 E1 = 2.777+08
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	7.27-02	1.032-02	1.076-02	5 - 20 M1 = 2.681+01, 9 - 20 M1 = 3.567+01
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	8.49-02	9.372-03	9.802-03	8 - 21 M1 = 8.564+01
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	6.36-09	5.001-09	2.423-09	1 - 22 E1 = 1.999+08
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	1.85-09	2.284-09	2.053-09	1 - 23 E1 = 4.379+08
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	5.67-02	4.334-03	4.507-03	5 - 24 M1 = 7.219+01, 8 - 24 M1 = 9.290+01
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	4.46-10	2.347-10	1.580-10	1 - 25 E1 = 2.247+09, 2 - 25 E1 = 2.013+09
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	2.20-08	5.985-09	3.420-10	1 - 26 E1 = 1.671+08
27	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	4.10-12	4.945-12	5.865-12	1 - 27 E1 = 2.008+11
28	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	5.24-12	5.828-12	6.450-12	1 - 28 E1 = 1.691+11
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	5.84-09	4.472-12	5.359-12	1 - 29 E1 = 2.236+11
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	3.75-12	5.717-12	5.005-12	2 - 30 E1 = 1.749+11
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	3.84-12	4.581-12	5.039-12	2 - 31 E1 = 2.097+11

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels

Table 16. Comparison of lifetimes (τ , s) for the lowest 31 levels of Mo VIII. $a \pm b \equiv a \times 10^{\pm b}$.

Index	Configuration	Level	GRASP2a	GRASP2b	GRASP3	GRASP2b (dominant A- values, s ⁻¹)
1	4s ² 4p ⁵	² P _{3/2} ^o	.....	.....	.....	.....
2	4s ² 4p ⁵	² P _{1/2} ^o	4.38-03	4.762-03	4.692-03	1 - 2 M1 = 2.096+02
3	4s4p ⁶	² S _{1/2}	3.36-10	2.785-10	3.299-10	1 - 3 E1 = 2.543+09, 2 - 3 E1 = 1.048+09
4	4s ² 4p ⁴ (³ P)4d	⁴ D _{5/2}	2.72-08	3.381-08	2.895-08	1 - 4 E1 = 2.958+07
5	4s ² 4p ⁴ (³ P)4d	⁴ D _{7/2}	6.75+01	1.638-02	1.752-02	1 - 5 M2 = 6.103+01
6	4s ² 4p ⁴ (³ P)4d	⁴ D _{3/2}	4.06-08	4.131-08	3.319-08	1 - 6 E1 = 2.393+07
7	4s ² 4p ⁴ (³ P)4d	⁴ D _{1/2}	4.83-08	2.867-08	2.339-08	1 - 7 E1 = 2.096+07, 2 - 7 E1 = 1.392+07
8	4s ² 4p ⁴ (³ P)4d	⁴ F _{9/2}	1.32-01	1.433-01	1.583-01	5 - 8 M1 = 6.968+00
9	4s ² 4p ⁴ (³ P)4d	⁴ F _{7/2}	2.99+00	3.734-02	3.994-02	1 - 9 M2 = 1.330+01, 5 - 9 M1 = 5.843+00, 8 - 9 M1 = 7.362+00
10	4s ² 4p ⁴ (¹ D)4d	² P _{1/2}	1.15-07	7.293-09	6.828-09	2 - 10 E1 = 1.110+08
12	4s ² 4p ⁴ (³ P)4d	⁴ F _{3/2}	3.61-09	8.512-09	6.312-09	1 - 11 E1 = 4.519+07, 2 - 11 E1 = 7.230+07
11	4s ² 4p ⁴ (³ P)4d	⁴ F _{5/2}	2.35-09	2.728-09	1.994-09	1 - 12 E1 = 3.666+08
13	4s ² 4p ⁴ (³ P)4d	⁴ P _{1/2}	6.82-10	7.747-10	7.081-10	1 - 13 E1 = 1.186+09
14	4s ² 4p ⁴ (³ P)4d	⁴ P _{3/2}	1.39-09	9.358-10	7.193-10	1 - 14 E1 = 1.066+09
15	4s ² 4p ⁴ (¹ D)4d	² D _{3/2}	2.02-09	1.340-09	1.084-09	1 - 15 E1 = 3.272+08, 2 - 15 E1 = 4.190+08
16	4s ² 4p ⁴ (³ P)4d	² F _{7/2}	1.58-01	7.107-03	7.278-03	5 - 16 M1 = 5.117+01, 8 - 16 M1 = 5.760+01
17	4s ² 4p ⁴ (³ P)4d	⁴ P _{5/2}	4.13-09	4.504-09	4.065-09	1 - 17 E1 = 2.220+08
18	4s ² 4p ⁴ (¹ D)4d	² P _{3/2}	1.61-08	1.247-08	1.770-08	1 - 18 E1 = 7.524+07
19	4s ² 4p ⁴ (¹ D)4d	² D _{5/2}	2.91-09	3.117-09	2.621-09	1 - 19 E1 = 3.209+08
20	4s ² 4p ⁴ (¹ D)4d	² G _{7/2}	4.15-02	6.123-03	6.396-03	5 - 20 M1 = 4.821+01, 9 - 20 M1 = 6.120+01
21	4s ² 4p ⁴ (¹ D)4d	² G _{9/2}	4.68-02	5.617-03	5.859-03	8 - 21 M1 = 1.429+02
22	4s ² 4p ⁴ (³ P)4d	² F _{5/2}	4.37-09	3.526-09	1.775-09	1 - 22 E1 = 2.836+08
23	4s ² 4p ⁴ (¹ D)4d	² F _{5/2}	1.39-09	1.702-09	1.658-09	1 - 23 E1 = 5.875+08
24	4s ² 4p ⁴ (¹ D)4d	² F _{7/2}	3.80-02	2.688-03	2.798-03	5 - 24 M1 = 1.116+02, 8 - 24 M1 = 1.581+02
25	4s ² 4p ⁴ (¹ S)4d	² D _{3/2}	2.99-10	1.682-10	1.155-10	1 - 25 E1 = 3.373+09, 2 - 25 E1 = 2.572+09
26	4s ² 4p ⁴ (¹ S)4d	² D _{5/2}	5.34-09	2.211-09	2.472-10	1 - 26 E1 = 4.523+08
27	4s ² 4p ⁴ (¹ D)4d	² S _{1/2}	3.55-12	4.120-12	4.808-12	1 - 27 E1 = 2.349+11
28	4s ² 4p ⁴ (³ P)4d	² P _{3/2}	4.41-12	4.849-12	5.472-12	1 - 28 E1 = 2.040+11
29	4s ² 4p ⁴ (³ P)4d	² P _{1/2}	2.65-10	4.884-12	4.777-12	2 - 29 E1 = 2.014+11
30	4s ² 4p ⁴ (³ P)4d	² D _{5/2}	3.17-12	3.725-12	4.209-12	1 - 30 E1 = 2.685+11
31	4s ² 4p ⁴ (³ P)4d	² D _{3/2}	3.25-12	3.823-12	4.240-12	2 - 31 E1 = 2.524+11

GRASP2a: Singh *et al* [16]

GRASP2b: present calculations from the GRASP code with 470 levels

GRASP3: present calculations from the GRASP code with 3990 levels